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DESIGN OF EXPERIMENTAL AREAS AND FACILITIES AT THE NATIONAL ACCELERATOR LABORATORY

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ABSTRACT

We describe in this report the plans and designs which have been developed for the experimental areas at the National Accelerator Laboratory. Plans for detector system facilities are also discussed.

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Special Note: The design ideas expressed in this paper have come from many sources. We have tried to draw the major elements of the design into this paper for use at the 1970 Summer Study.

I. INTRODUCTION

During the past several months, detailed plans for the layout of the experimental areas have been developed. A specific spectrum of secondary particle beams is now planned, and detailed beam designs are now being worked out. Ideas concerning possible high energy physics experiments have played an important role in the formation of these plans. A further survey of the complete set of proposals for experiments will be a major factor in the final determination of this array of beams.

We have also studied various possibilities for detector systems and other experimental facilities needed for the implementation of the high energy physics research program at NAL. A definite decision has been made to construct a cryogenic bubble chamber of about fifteen foot length for use in early 1973. Other special detector facilities are expected to be built once decisions have been made concerning the initial round of experiments to be done at the accelerator. Some of those facilities will certainly be built at NAL; others may be built by other laboratories or by groups working at universities. These plans can be expected to become definite following the NAL Program Advisory Committee meeting of August 1970.

The arrangement of this report is as follows. In Section II, we outline what presently appear likely to be the most fruitful areas of experimental work at NAL. These ideas in turn suggest what are desirable secondary beams and detector facilities. A general description of the planned experimental areas and facilities to accommodate these experimental programs is given in Section III.

A dominant factor which will determine the scope and nature of the research program is the performance of the accelerator as a source of high energy protons. So in Section IV we describe some of the planned operating characteristics of the 200-500 GeV accelerator which most directly affect the nature and operation of the experimental program. We discuss the extraction systems for the accelerated proton beam and the systems which will be used for targeting and dumping of the proton beams in the secondary beam areas.

In Section V, there are discussions of the planned scope of the high energy physics research program and of the spectrum of secondary beams which we have recommended for what we believe to be an optimal implementation of the physics program. In Section V we give a brief description of the designs of Experimental Area #2 and Experimental Area #1, together with a brief mention of typical experiment set-ups in the various secondary beams.

In Section VI we consider detector facilities for the implementation of the high energy experiments. In particular, we discuss the 15-ft. bubble chamber design and construction work, and some other likely detector systems and data analysis facilities.

Project schedules and preliminary cost-estimates are discussed in Section VII, and in Section VIII we describe some of the available options for possible future expansion of the accelerator and of its associated research facilities.

II. BRIEF DISCUSSION OF POSSIBLE EXPERIMENTS

Physics experiments to be done in the 100-500 GeV range have been discussed widely during recent years, (for an extensive bibliography, see the 1968 and 1969 Summer Study Reports). We will attempt to summarize briefly some of these discussions in the next paragraphs, while recognizing that to predict precisely what will be the most significant experiments would be a foolhardy endeavor.

Here is a list of likely significant experiments:

1. Searches for new particles--monopoles, quarks, tachyons, W's, etc.
2. Total and differential-elastic hadron-hadron and hadron-nucleus cross-sections with attention to asymptotic behavior.
3. Deep inelastic hadron and lepton scattering (technically this is similar to beam survey and particle production measurements).
4. Neutrino interaction phenomena at high energies.
5. Weak interaction form factor determinations using medium-energy neutrinos.
6. Detailed studies of inelastic channels for ν-interactions.
7. Extension of SLAC studies of quantum electrodynamics at large ν and q^2 (using μ's, e's, and γ's).

8. Hyperon production, interactions, and decay studies (increasingly practical at high energies when hyperon lifetimes become relatively large in the laboratory-frame).
9. K^o decay and regeneration studies.
10. Search for resonances produced in high-energy collisions and studies of their characteristics.
11. Survey-type physics of hadron-hadron interactions in a bubble chamber--with beams of p, $\bar{p}$, π^-, π^+, K^-, K^+, etc.
12. Studies of specific hadron-hadron reaction channels other than the elastic channel; $pp \rightarrow pN^*$, $\pi p \rightarrow p\rho$, etc.

III. SCOPE AND GENERAL DESCRIPTION OF THE EXPERIMENTAL AREAS

We are planning an arrangement of experimental areas, shown in Figures 1, 2, and 3 which we believe can accommodate many of the research program possibilities we have discussed above. The design of Area #3 has not yet begun. In that area we expect to accommodate new beams not presently envisioned at all, together with "500-GeV" secondary beams resulting from the routine use of 500 GeV protons from the accelerator in future years.

The planned scope of the experimental physics program at NAL has already been spelled out in the January 1968 NAL Design Report. The estimated size of the research program, two to three years after accelerator turn-on, is given in Table I.

Table I. Estimated Research Program Capacity in 1974

Number of Target Stations	=	3
Number of Beams for Electronic Experiments	=	7 - 10
Number of Beams for Bubble Chamber Experiments	=	2
Number of Beams in Operation	=	9 - 12
Number of Experimental Set-ups	=	12

The list of secondary beams that is discussed in the following sections is consistent in all respects with the statements in Table I. Of course, it should be recognized that technical or financial complications may eventually modify the goals outlined in this report.

The next step in the design of the experimental facilities consists in making a final choice of the secondary beams to be included. We started by considering the beams of highest initial priority, we have adopted the following guiding philosophy-namely, that these four beams should correspond to a reasonably complete set of beams so that the initial research program at NAL can be rather varied. This approach is to be compared with, and is preferred to, an early emphasis on any one particular facet of the research program.

The four highest-priority beams in Areas #1 and #2 are:

(i) High-energy, high resolution, unseparated hadron beam.

(ii) 200 BeV secondary proton beam, including a neutral particle beam branch.

(iii) High-energy neutrino-muon beam with long and short spill.

(iv) High-intensity, high-energy beam.

The specification of additional beams in Areas #1 and #2 is much more difficult. It is proposed to complete the variety of the spectrum of beams at NAL with the following choices:

(v) High-energy rf-separated beam.

(vi) A second neutral beam such as K_L^O's.

(vii) Moderate-resolution unseparated hadron beam for momentum up to $\approx$ 75 GeV/c, which includes the peak in the secondary π and K intensity spectrum at about 40 GeV/c.

(viii) Special beams such as hyperons or K_s^O's that need unusual targeting arrangements.

By the use of series and/or parallel branches in these beams and the use of Area #3, it will be possible to accommodate the twelve set-ups that are planned. The proposed set of secondary beam lines is presented in Table II. This table also shows the target area at which we propose to install each beam.

Table II. Secondary Beams in the Experimental Areas

Area #2	
Beam 1	High energy, high resolution.
Beam 2	Proton beam with reduced intensity.
Beam 3	Neutral beam for neutrons or K_L^o's.
Beam 4	Medium energy, moderate resolution.
Beam 5	High energy, high intensity.
Area #1	
Beam 6	High energy neutrino/muon beam.
Beam 7	Medium energy rf-separated beam.
Beam 8	Hadron beam using the muon channel.
Area #3	
Beam 9 and more	Special purpose beams that make use of 500 GeV protons.

A more detailed discussion of each of these secondary beams is given later in Section V.

IV. OPERATING CHARACTERISTICS OF THE 200-500 GeV ACCELERATOR AND ASSOCIATED BEAM-EXTRACTION, TARGETING, AND DUMPING SYSTEMS

In this section we discuss a number of characteristics of the 200-500 GeV machine which are of particular major importance to the experimental use of the accelerator. These include a discussion of the accelerator energy, intensity, and the emittance properties and time-structure of the extracted proton beam. We also discuss the targeting and dumping of the 200-500 GeV protons.

Accelerator Energy

The single most important characteristic of the accelerator is the energy to which protons are accelerated. Although it will be possible in special instances to operate the accelerator, from the beginning, at 500 GeV, this will be at reduced repetition rate and low duty factor--nevertheless the routine operation of the accelerator will initially be at 200 GeV. During the first year of experimental program operations, it is expected that fast and slow extraction up to 400 GeV will become possible. Initial operation with 500 GeV protons will be either with a fast extracted external beam or with the use of internal targets at reduced intensity. The useable phase space within the accelerator magnet structure for 500 GeV protons is quite small, and the internal circulating beam is likely to behave in an erratic fashion during resonant extraction. The lowest energy at which the full accelerator proton beam can be efficiently extracted is about 50 GeV.

Intensity

The design intensity of the 200 GeV accelerator is 5×10^{13} protons/pulse. The planned accelerator cycle for long spill at 200 GeV proton energy, is four seconds in length, including a 1 second flat-top for electronics experiments. This corresponds to a duty factor of 25%, with an instantaneous proton beam intensity of 5×10^{13} protons/sec, and an average intensity of 1.3 x 10^{13} protons/sec.

At 400 BeV proton energy, where both fast and slow extraction will be possible, the accelerator cycle will be almost twice as long as at 200 BeV; the average proton current will be about 0.7 x 10^{13} protons/sec. At energies ∿500 GeV, the cycle will be even longer; slow-spill experiments will initially be done using internal targets.

At all energies, the minimum fast-spill length will be 60μsec.

Properties of the external proton beams

The emittances and duty cycles of the external proton beam, at various synchrotron energies, are shown in Table III. At all energies the energy resolution of the proton beam is ~ 0.01%.

TABLE III. Proton Beam Characteristics

Energy	Spill	$E=\pi ab$ horiz. a b	$E=\pi cd$ vert. c d	Duty Cycle
50	Slow	1mm x 1 mr	1 mm x 1.5 mr	~ 75%
200	Fast	1mm x 0.7mrad,	1mm x 0.3mrad	
200	Slow	1mm x .2mrad,	1mm x 0.3mrad	~ 25%
400	Fast	1 mm x .3 mrad	1mm x .2 mrad	~ 10%

At a given energy the emittances defined by ellipses with area defined $E_h = \pi ab$ and $E_v = \pi cd$ are fixed. However, with the use of an appropriate set of quadrupole focusing elements, it is possible to raise (and lower), in inverse proportion to one another, the size and divergence of the beam incident upon a given production target.

Time Structure in the Proton Beam

The circulating proton beam in the main accelerator consists, at 200 GeV energy, of about 1,000 rf bunches, each of 2nsec width, and spaced 20nsec apart. With the installation of appropriate kicker magnets in the main accelerator ring, one or a number of these bunches can be extracted -- for example, to provide for a short-pulse beam for a pulsed-cavity rf-separated beam to a bubble chamber.

In addition to this fast extraction of part or even all of the proton beam,

it will be possible to control and vary the rate of the slow extraction of the beam. As an example, it will be possible to superimpose on the slow beam a number of 'quick' (perhaps 1 millisecond long) bursts of protons, for example once every 0.1 sec, to provide a beam to a 10 Hz rapid-cycling bubble chamber.

Also, it will be possible to modulate a secondary particle beam channel, which is operated normally as a d.c. transport system, so that a kicker-magnet system--either at the production target or near the end of the secondary beam line--can provide the desired bursts of hadrons to supply a bubble chamber.

Beam Targeting and Dump

The designs of targets and beam dumps for proton beams at the NAL accelerator are vital features of the overall design. The magnitude of the problems can be recognized by taking note of the fact that the energy in a beam of 5 x 10^{13}, 200 GeV protons is about 400 kilo-joules. This gives rise to tremendous heating problems for targets and beam dumps, and the levels of induced radioactivity in these elements and in their associated cooling systems will be correspondingly high. We note that the beam power at NAL is approximately two orders of magnitude greater than the beam power at the AGS of Brookhaven.

Arrangements for Targets and Beam Stoppers

In both Areas 1 and 2 the proton beam hits the primary targets while inside a target box. This structure is made of iron and is covered by earth to provide shielding. The inside dimensions of the target box in Area 2 are 44 in. x 44 in. by 80 feet long. Components are moved into this box on railroad cars. Because the radioactivity of the target and beam stopper will be 1000r/hour when removed from the box, it is necessary to be able to make adjustments to the target and other elements by remote control. This will be accomplished by being able to remove the target train from the box by remote control, and bringing it into an area serviced by mechanical manipulators and cranes.

Figure 4 is an illustration of how the targeting arrangements might look in area 2. The target is about midway in the box. This provides space upstream from the target for the location of special magnets. These magnets will be used to manipulate the proton beam before it hits the target. In this way the angle of production of secondary particles in fixed beam lines can be changed.

Following the target at Area No. 2, there is a free space of nearly 20 feet, then 12 feet of hadron shielding to serve as a beam stop. There are fixed holes through this shield corresponding to the ports for four secondary beams emerging from the target. The remaining space within the box will be used by variable collimators in each of the beam lines. The apertures of these collimators will be set to provide the necessary flux of secondary particles into the experimental area. When a beam is not being used, these collimators will be closed.

V. EXPERIMENTAL AREAS #1 AND # 2

These areas have been designed around the specific sets of beams discussed earlier. The beam lines begin at the target in the box and proceed through underground tunnels until emerging into experimental buildings and detectors at the ends. The problems do not end there, since some of the experiments will be 500 feet long, and must be followed by earth filters to reduce the intensity of beam-line muons to tolerable levels. A detailed description of each area and its beams will follow.

EXPERIMENTAL AREA 1

Introduction and Scope

The major feature of Area 1 is the neutrino beam with its 600 meter long decay length for π and K mesons and 360 meter long iron shield to stop μ mesons. The beam line is roughly at ground elevation and therefore requires a massive 30 ft. high and 100 ft. wide earth shield running about 1000 meters for radiation purposes. The general outlines of the area are shown in Fig. 5.

This area, its beam transport, shielding, etc., are being designed for the use of 500 GeV protons. The problems of providing adequate shielding for satisfactory operation of a large bubble chamber detector will be severe; however, if sufficient funds are available for the requisite shielding, the area will be built to accommodate bubble chamber operations using 500 GeV protons.

Some of the muons produced in the decay region will be used to produce an intense ($\sim 10^6$ - 10^7 muons per pulse) beam at energies up to 300 GeV. An interesting feature of this beam is its high and controllable degree of longitudinal polarization.

The third beam planned for Area 1 is an rf separated beam with maximum momentum capability of 90 GeV/c. It is likely that the initial operation of this beam will be such that $K\pi$ separation will be achieved only up to 50 GeV/c.

Physical Layout

The proton beam is transported to Area 1 at a slight upward pitching angle and then made horizontal at an elevation of 745 ft. The beam transport magnets will be able to transport 500 GeV/c protons in the initial operation of the area. The horizontal proton beam enters a pre-target underground enclosure which is covered by about 20 ft. of earth for radiation shielding. At the downstream end of this enclosure the proton beam enters a steel box whose inside dimensions are 44 in. wide and about 60 in. high. The box extends for 200 ft. along the beam direction. Various magnetic focusing devices will be able to be installed within this steel box for purposes of focusing the π and K parents of the neutrino beam. Following the box there is a 600 meter long steel pipe 3-feet in diameter which is evacuated and in which the pions and kaons are allowed to decay. At the downstream end of the decay pipe a high power beam dump will be installed. Immediately following, there is a 360-meter long 10 ft.x 10 ft. steel shield to stop high energy muons. Surrounding the steel there is the continuation of the 30-ft. high by 100-ft. wide earth cover.

Brief Discussion of Beams

1. Neutrino Beam.

The 500 GeV incident proton energy allows between one and two orders of magnitude in neutrino flux in the 100-150 GeV neutrino energy range compared to previous discussions with 200 GeV protons. This increase is after due allowance for reduction in repetition rate has been taken into account.

This represents, therefore, essentially a qualitative difference in the neutrino beam from the discussions of last year. We have spent some time this year investigating various focusing devices associated with the neutrino beam and their effects on neutrino flux.

2. Muon beam.

The muon beam will have a maximum energy of 300 GeV/c and have an intensity of roughly 5×10^6 μ/pulse in ±2-1/2% momentum interval. The longitudinal polarization can be varied with some loss in intensity. This beam can also be used for proton and pion transport up to 300 GeV/c.

3. R.F. Separated Beam.

Two modes of operation of the RF beam are being planned. First, the beam can be operated with a transmission target and can transport approximately 10^3 K^- or $\bar{p}$ and 10^4 K^+ per pulse. Thus, the bubble chamber requirements can be satisfied with a small fraction of the full beam intensity. This mode of operation will be possible simultaneous with neutrino and muon beam operation.

Secondly, for very high intensity separated beam work we will be able to run with a thick target and increase the separated K^- and $\bar{p}$ flux to about 10^6 and K^+ to 10^7 per pulse.

EXPERIMENTAL AREA 2

Introduction and Scope

Area 2 will be used to provide a variety of general-purpose secondary beams for repeated use by experimenters. These beams are as follows:

- a high-energy (up to 200 GeV/c), high-resolution ($\Delta p/p = \pm 0.04\%$) unseparated hadron beam;
- a diffracted proton beam (200 GeV/c);
- a neutral beam (with variable production angle between 1.5 mrad and 10 mrad)
- a high energy (up to 150 GeV/c) high intensity ($\sim 10^8 - 10^9$) π beam; and
- a medium-energy (up to 80 GeV/c), good resolution ($\Delta p/p = \pm 0.1\%$) unseparated hadron beam.

These five secondary beams are produced at a common production target, and are transported underground to a 200' x 150' building for housing the experiments. This building is situated at the downstream end of an approximately 1,000-ft. long earthen shield which is required to attenuate the background muon flux to a tolerable level for personnel protection.

Area 2 is designed for use with 200 GeV/c incident protons. The provision of beam transport elements, muon shielding, etc., are planned with this upper energy limit in mind.

Layout of Area 2

A plan view of the layout of Area 2 is shown in Fig. 6. The extracted proton beam from the accelerator is transported to Target 2 at a slightly upward pitching angle and is then bent (almost) horizontal at an elevation of 746 ft. The proton beam passes through a pre-target underground area which is covered by about 20 ft. of earth for radiation shielding. At the downstream end of this enclosure the proton beam enters a steel box ("target box") whose inside dimensions are 44 in. wide by 60 in. high. The target box extends 80-ft. along the beam direction. The production target for the secondary beams is located 45 ft. from the downstream end of the box.

Bending magnets placed upstream of the production target are used to vary the angle of incidence of the proton beam upon the target, thereby making it possible to vary the production angles of the secondary beams. Immediately downstream from the target, a special target-magnet makes it possible to attain 0° production of the charged secondary beams.

Following the production target, the unused protons and the unwanted produced hadrons are stopped by a beam dump and a hadron shield. The secondary beams pass through variable-aperture collimators which serve as crude secondary-beam intensity controls. The upstream beam-line components-septum dipoles, transport dipoles and quadrupoles, etc., are housed in a 220-ft. long underground vault which is covered by some 20-ft. earth for radiation shielding purposes.

Upon leaving the vault, the individual secondary beams pass through small enclosures--connected where there are no active beam-line elements by sections of vacuum pipe. In this region, beam-line enclosures are covered by the earthen shield of average radius 18 ft., and length about 1000 ft. This shield is required to stop the muons which arise from π and K meson decay.

At the end of the muon shield, the four charged beams and the neutral beam emerge into an experimental hall of 200 ft. width and 150 ft. depth. Experiments will be set up in this building side by side, with appropriate radiation background shielding between them. For experiments whose length is greater than 150 ft., special auxiliary structures will be built to house the apparatus.

Brief Discussion of Secondary Beams

Table IV gives a summary of the properties of the five secondary beams.

1. High energy, high resolution beam (HEHR)

This beam is produced at an angle of 2.5 mrad, can be tuned over the momentum-range 20-200 GeV/c, and is designed to have a momentum resolution capability ($\Delta p/p = \pm 0.04\%$). This is a 3-stage beam. In the first section, the beam is imaged onto a slit with a dispersion of about 4 cm/%$\Delta p/p$; by opening up the momentum slit, a maximum transmission $\Delta p/p = \pm 1\%$ can be obtained. In the second stage, the beam is focussed onto vertical and horizontal clean-up slits. In the final stage of the beam, there is momentum recombination. In this third section, it will be possible to install detectors to form an incident beam spectrometer for a scattering experiment which uses this beam. A typical beam intensity would be 10^7 π^- (100 GeV/c) per pulse.

2. Neutral beam (K^o/n)

The neutral beam is produced at an angle of 1.5-10 mrad; this angle is varied by rotating the angle of incidence of the

TABLE IV. Parameters for Area 2 Beams

No.	Name	Typical Momenta	Particle	Intensity/Pulse	$(\Delta p/p)_{FW\%}$	$(\Delta\Omega)_{\mu sr}$	θ_{Prod}(mrad)
1	High energy, high intensity	150 (GeV/c) 100 (GeV/c)	π^- π^-	$\sim 10^7 - 10^8$ *** $\sim 10^8 - 10^9$ ***	0.2-5 0.2-5	4 4	3.5 3.5
2	Proton beam (reduced intensity)	200	p	$\sim 10^{10}$	0.01*	0.2	1
3	Neutron beam	150-200 100-150	n n	$\sim 10^7$ $\sim 10^7$	** **	0.2 0.2	1 1
4	High energy, high resolution	150 100	π^- π^-	$\sim 10^6$ $\sim 10^7$	0.1 0.1	1.5 1.5	2.5 2.5
5	Medium energy, moderate re- solution beam	75 50	π^+ π^+	$\sim 10^6$ $\sim 10^7$	0.1 0.1	10 10	15 15
6	Neutral beam (tentative)	50-75 25-50	K_L^o K_L^o	$\sim 10^5$ $\sim 10^4$	** **	0.2 0.2	5 5

* 0.01% = $\Delta p/p$ = assumed $\Delta p/p$ of slow-extracted 200 GeV proton beam.

** No momentum selection is, of course, possible in a neutral beam; intensity is given for a 1 GeV/c momentum interval.

*** Intensity depends upon choice of $\Delta p/p$.

proton beam on the production target. At 200-ft. from the production target, There is a sweeping and collimation section in the beam. At a distance of about 600-ft. from the target, there is provision for a second sweeping and collimation section. The relative fluxes at K_L^o 's and neutrons in the beam are controlled by choice of the beam production angle. A typical beam intensity would be 10^7 neutrons/GeV/pulse. A second neutral beam at a nominal production angle of 5 mr is being studied.

3. Diffracted Proton Beam (DPB)

The diffracted proton beam uses the same production channel as the small angle neutral beam. The first sweeping elements in the neutral beam deflect the diffracted protons into a separate beam channel. The proton beam is dispersed and focussed onto cleanup slits about 600-ft. from the production target. In the second-half of the beam, momentum recombination of the beam in both position and angle is effected. The maximum allowed intensity of this beam will be dictated by radiation shielding needs and problems in the experimental area--a maximum intensity on the order of 10^{10} protons/pulse is anticipated. This beam feeds what may be termed a "medium intensity end-station" for studies of p-p interactions and studies of short-lived particles.

4. High Energy, High-Intensity Beam (HEHI)

This beam is produced at 3.5 mrad with respect to the incident proton beam, and has a maximum momentum capability of 160 GeV/c. By contrast with the high-resolution-beam, emphasis here is placed on intensity rather than resolution. The beam will eventually have a large solid angle of acceptance (2x) and a larger $\Delta p/p$ acceptance capability (3x) than the 2.5 mrad secondary beam. The 3.5 mrad beam is a 3-stage beam, with the 3rd stage being available to make a tertiary beam--e.g., a filter to produce a purified muon beam, or a target system to make a K^o beam which is relatively neutron-free. Provision for conversion of the π beam to an electron beam and an associated tagged γ-beam will also be made. A typical π intensity in the beam would be 10^9 π (100 GeV/c)/pulse.

5. Medium energy, high resolution beam (MEHR)

This beam is produced at 15 mrad, has a maximum energy capability of 80 GeV/c, and a design momentum resolution of $\Delta p/p = \pm 0.1\%$. This beam covers the peak in the predicted momentum spectrum of π's and K's (40-60 GeV/c) and thus will be simultaneously both a high-intensity beam and a high-resolution beam. Like the 2-1/2 mrad beam, this is a 3-stage beam with dispersion, cleanup, and incident-beam-spectrometer sections. A typical beam intensity would be 10^7 π^- (50 GeV/c)/pulse.

Experimental Area No. 3

The initiation of design of Experimental Area No. 3 is expected to be deferred for some time, perhaps until after some operating experience and research results have been obtained from Areas No. 1 and 2. It may then be possible to develop better design areas based on this experience, and to incorporate new, presently unanticipated beams which appear to be desirable on the basis of the early experimental results from the NAL Accelerator.

Experimental Arrangements

We have described the targeting, shielding, and beam transport that brings the secondary beams into regions suitable for doing experiments. In both Areas 1 and 2 the various secondary beams emerge into an experimental hall. In Area 2 the beams are spaced apart about 30-40 ft. from one another so that adequate shielding and personnel and vehicle access can be achieved. The hydrogen targets and large aperture magnets would be contained within an experimental hall at the end of the beam lines. It has been estimated that an area approximately 200 ft. wide by 150 ft. length would be needed for this purpose. It is recognized that most of the components used to measure the energy of the forward going particles will extend out of the experimental hall. These components and detectors will then be housed in temporary structures radiating out from the building.

Definite construction plans for the detector areas and the required apparatus for doing experiments will be developed following the Fourth NAL Summer Study Program, to be held at the Batavia site in June and July 1970. In the summer and early fall of 1970, the first round of proposals for research experiments at NAL will be considered. The experimental equipment to be built will be determined by the Laboratory in the fall of 1970, based on the requirements of the experiments that are chosen to be done first in Experimental Areas No. 1 and 2.

However, in order to help provide a definitive basis for discussions of experiments and experimental facilities, we have studied a number of possible configurations of experiments.

Area No. 2 Experiments

An example of a possible layout of experiments, detection systems, and housings for Experimental Area #2, is shown in Fig. 7. In this example, the experiments, reading from top to bottom of Fig. 7, are:

(1) Medium energy - good - resolution beam experiment, such as study of boson and fermion resonance production (and decay distributions) in πN interactions: multiparticle spectrometer.

(2) High-resolution beam experiment, such as $\pi N \rightarrow \pi N^*$ and $NN \rightarrow NN^*$ in the 200 GeV range (high resolution forward spectrometer).

(3) K_L^o beam experiment, such as measurement of $\Delta\sigma_T$ ($\bar{K}^o - p$, $K^o - p$) as a function of energy; use of a $K^o \rightarrow \pi^+\pi^-$ 2-particle spectrometer.

(4) Neutron beam experiment, such as forward and backward np elastic scattering; neutron calorimeter equipment.

(5) 200 BeV proton beam experiment such as production survey of Σ^+ and Ξ^- hyperons and study of their decay modes: this special Y-experiment uses a short-length, high-magnetic-field spectrometer.

(6) High intensity beam-branch experiment (e.g., $\mu^\pm$, $e^\pm$, γ, K^o), such as inelastic scattering of muons, use of high-energy forward muon spectrometer.

Area #1 Experiments

An example of a possible arrangement of experiments, detection systems, and housings in Experimental Area #1, is still being developed. In current example, the experiments are as follows:

(1) The 15-ft. bubble chamber can be exposed to beams of any of the following:

(i) ν or $\bar{\nu}$

(ii) unseparated hadrons up to 300 GeV/c.

(iii) separated π^{+}, $K^{\pm}$, $\bar{p}$ up to 100 GeV/c.

(2) Neutrino-interaction or muon-interaction experiments in a large-mass hadron calorimeter and muon detector.

(3) Future possibilities indicate a branch in the μ beam to another counter experiment, and a counter experiment in a branch of the rf separated beam, when (in the future) this beam is equipped with c.w. deflecting cavities.

Beam Transport Equipment and Housings

In this section, we shall discuss the use of main-accelerator magnets in secondary beam lines, and the development work at NAL on superconducting beam-transport equipment.

Use of main accelerator magnets in secondary beam lines

With the exception of the special septum magnets which are needed in the upstream ('front end') sections of the secondary beam lines, where there is very close spacing between these beam-lines, main accelerator dipole (both B1 and B2) and quadrupole (Q4 and Q7) magnets appear to be suitable for use in all the charged secondary beam lines that we have discussed previously.

The B2 main ring dipoles are 19 ft. 11 inches long with outside dimensions of 24 inches wide by 14 inches high. The inside aperture is 2 inches by 4 inches wide. When powered by a current of 4000 amperes the magnetic field is 15 kilogauss. The parameters of the main ring magnets are noted in Table V.

Development of Superconducting Beam Transport Equipment

We have undertaken a development program for superconducting magnets and associated equipment, for future use in secondary beam lines.

a. "Superferric Dipole"

A 3-ft. long model dipole magnet, with an iron core (cooled to 4.2°K) to determine field shape characteristics ("superferric" magnet) has already been built and tested. A sample of the magnetic test data and the major parameters of the magnet are given in Table VI. A 10-ft. long prototype is now under construction; assembly should be completed in June 1970. The field in this magnet is designed to be uniform to 0.1% over 4" aperture, for fields up to 20 kG. The magnet is expected to be useable at fields up to ~ 25-28 hG.

b. "Superferric Quadrupole"

A superferric quadrupole magnet, designed to be a good match to the superferric dipole, is being designed. This magnet will have 4" diameter bore, a gradient ~ 5-6 kG/in, shaped iron pole tips; the iron core would be at 4.2°K as in the case of the superferric dipole. We are studying an alternative design with asymmetric acceptance - perhaps a 3" x 5" aperture. Final design of a prototype quadrupole magnet will start in June 1970.

TABLE V

Parameters of Main Ring Magnets

	DIPOLES		QUADRUPOLES	
	B1	B2	Q4	Q7
outside dimensions	14-1/2" x 24-1/4"	same as B1	25-1/4" x 17-1/4"	same as Q4
length of steel	239"	239"	52"	84"
weight in lbs.	24,600	24,200	5700	8600
Aperture	1-1/2" x 5"	2" x 4"	3.4 x 4.75"	3.4 x 4.75
resistance	5.92 mΩ	7.16 mΩ	2.88 mΩ	4.4 mΩ
inductance	6.47 mH	7.96 mH	.98 mH	1.6 mH
field	8.96 Kg at 2294 amps 17.88 Kg at 4704 amps		1.25 Kg/cm at 2166 amps 2.50 Kg/cm at 4500 amps	

c. "Cos2θ-wound quadrupole"

A model cos-2θ type air-core quadrupole is being assembled in our laboratory. It should be ready for magnetic field tests by July 1970. This model is 2-ft. long, with a design gradient of 10 kG/in, a gradient uniformity of 0.2% over 4" diameter - with a total available beam aperture of 5" diameter.

d. "Cos θ-wound Dipole"

A 10-ft. long prototype cosθ-winding air-core prototype superconducting dipole magnet is being constructed by Airco-Temescal; assembly of the magnet should be completed in September 1970. This magnet has a design field of 35 kG and is to have uniformity of 0.2% over 4".

Until the development programs for superconducting beam transport magnets have advanced much further, it is not practical to decide where and to what extent to employ these magnets in the beam lines. However, two specific possibilities have been suggested and are presently under serious consideration:

(i) Muon beam in experimental Area #1; and

(ii) Final section of RF separated beam in Area #1.

An important consideration here is that these two beams are located quite close to the 15' bubble chamber facility which will include a large superconducting magnet and associated cryogenic facilities.

VI. DETECTORS AND ASSOCIATED FACILITIES

The experiments and beams that will be set up in the experimental areas at NAL will require a variety of particle detectors, analysis magnets, computers, and associated equipment. In this section we discuss the following topics:

1. Instrumentation for secondary beams including beam monitoring, control, and detectors required to identify beam particles incident to experimental apparatus.

2. Equipment for electronic experiments including a brief description of analysis magnets, track detectors, readout logic, and computers.

3. Plans for bubble chambers and associated facilities

1. Beam Instrumentation

Instrumentation of secondary beam lines can be divided into two categories. One category provides information on the qualities of the composite beam while the other provides information on the individual particles within the beam. The rates at which the latter can operate will in general be not greater than 10^7 particles sec^{-1} depending upon the contamination and time dependent intensity structure within the beam. As we shall see, instrumentation for composite information about the beam can be rather simple. Because of various sources of background and beam contamination, interpretation of this information may be complicated enough to cause problems in computer monitoring. The nature of this problem will become more apparent in the example discussed below. It should also be noted that the upstream and of all secondary beams will utilize the composite monitoring because of the high flux. Only in the last stage or stage and a half, will digital information particle by particle be required and then for only certain experiments.

Composite Beam Monitoring

The 15 mr beam line isused as an example of a beam line that must contain the instrumentation necessary to tune and monitor the beam. The flux rates range from 10^{10} particles per pulse at the source to 10^6 at the end.

In general the instrumentation should provide the necessary information to allow the beam to be threaded through the system on the axis of the optical elements, and will provide data on transport efficiency and slit attenuation. In contaminated beams, this information would remain useful in tuning and monitoring the line. Ideally, the PIPS (Profile, Intensity, and Position System) at the entrance to the first quadrupole would indicate the profile of the aperture of the upstream bending magnet; however, the background from the other beams, diffracted beam, etc., may make the profile unrecognizable so that the information there may have little relative use.

Vernier bending magnets, both horizontal and vertical, should be added at the appropriate positions to assist in aligning the beam at critical points such as the entrance to quadrupoles, slits, and at the final target. The strength of the vernier magnets should be adequate to displace the beam the equivalent of 2 FWHM of the momentum bite at slits, approximately 0.1 FWHM beam size at the entrance to a quadrupole and 2 FWHM at the target. Providing the profiles are relatively easy to interpret, computer monitoring of beam position with computer control of the appropriate vernier magnets would permit long term stability of beam positions at these critical locations.

Finally, instrumentation is indicated to provide the user with information on the divergence, size, position, and intensity of the beam at his experiment.

The type of instrument which may be adequate for all composite beam monitoring is the parallel wire ion chamber. At fluxes of $\sim 10^6$ particles sec^{-1}, the acquisition period may be approximately two minutes i.e. two minutes would be required to obtain a profile. At fluxes of 10^9 or so, a useable profile may be obtained each machine cycle.

The paralled wire ion chamber will provide information on beam size, position, and intensity information simultaneously. Size and position information may be provided with spatial resolution of a fraction of mm, the precision depending upon the symmetry and contamination of the beam.

Individual Particle Detection

Experiments which require knowledge of the beam purity and kinematics of individual particles require more complicated instrumentation and reduced fluxes. Threshold and DISC type Cerenkov counters will need to be used for particle identification. Scintillation counter hodoscopes and proportional wire chamber arrangements will be used to count the charged beam particles and to determine their trajectories.

Where a knowledge of the momentum of the identified particle is essential, then further reductions in available flux are necessary if the momentum re-analyzing section does not follow the last slit. This reduction in intensity will depend significantly on the momentum bite which is used so that intensity attenuation factors of 10 to 100 are anticipated for some experiments.

2. Equipment for Electronics Experiments

The equipment required for counter experiments and electronic detection systems indicates various configurations of a number of specific kinds of items.

(i) Analysis magnets for charged-particle momentum measurements, and associated power supplies and controls.

(ii) Track detectors for the measurement of charged-particle trajectories-spark and wire chambers, counter hodoscopes, etc.

(iii) Fast trigger detectors and trigger logic-scintillation counters, Cerenkov counters, shower detectors, etc.

(iv) Readout logic and computer interface equipment to transmit the trigger information and track chamber information to an on-line data recording and monitoring computer.

(v) An on-line computer, and data processing facility.

In many instances, an array of equipment in one of the secondary beam-lines will be sufficiently complex or expensive, or both, to become identified as a laboratory facility. Thus, much of the equipment will be used in the same beam-line for a number of experiments, with only minor rearrangements of the apparatus between one experiment and the next.

(i) Analysis Magnets

We identify analysis magnets in three categories:

(a) Large-aperture magnets associated with a relatively fixed detector system installation

An example of such a large-aperture magnet is the analysis magnet which is to be built in conjunction with the fifteen-foot bubble chamber. As other large detection systems are approved for construction, the associated special large-aperture analysis magnet will be included in these projects. Long-term possibilities include a magnet to surround a streamer chamber vertex detector facility; an analysis magnet in conjunction with a small, high-precision bubble chamber; and the analysis magnet which would be the central feature of a large-aperture multiparticle detector system for study of details of high-energy inelastic-scattering and resonance production processes.

(b) Beam-transport magnets

Magnets of the type used for secondary beam-line transport systems are also expected to be used in small-aperture spectrometers (whether focussing or non-focussing) used for the detection and analysis of charged high-energy scattered particles from high-energy collisions. Examples of such magnets are the dipole and quadrupole magnets used in the main accelerator, and in the secondary beam lines. Their principal parameters are given in Table V.

(c) Portable Magnets

Portable magnets of various lengths, apertures and field strengths would be used in conjunction with the previous two types of magnets, or sometimes used indepently to form simple analysis systems. Examples of these magnets are the 48D48 magnets at BNL. The specific choices of these magnets will be deferred until experiments requiring them have been selected.

(ii) Track Detectors and Readout Systems

Optical chambers used as detectors can be read out onto photographic film or electrically on-line via television techniques. In either case one has the problem of mirror alignment, stereo angles and visual accessibility. These systems have a comparatively long readout, or recovery time. In principle a fast (30 millisecond) 35 mm camera has a very high bit-recording rate (equivalent to hundreds of megacycles); but most of the frame area is blank, yielding a rather slow rate for useful data. The same is true of television systems.

The principal disadvantage of photographic techniques is the problem of translating the data from film to a form a computer can read. For some detectors, of course, no other system is practical. The use of a rapid cycling bubble chamber or a streamer chamber in the vertex region of a complex event is very attractive. These chambers are relatively portable and can be mounted as targets for particular experiments in spectrometer installations.

Development in recent years of various types of detectors with direct electrical readout has been largely motivated by the desire to know promptly how the experiment is progressing. We shall discuss the characteristics and uses of these detectors in turn. It should be remembered that the data handling methods for all are the same in our context; they are all digitizing planes.

Wire spark chambers are a direct outgrowth of narrow gap optical spark chambers. As the gaseous multiplication processes are the same so are the inherent spatial and time resolutions and the recovery time: approximately $\pm$ 0.2 mm, a microsecond and a millisecond respectively, being gas filled they produce minimal multiple scattering, and they can be made to cover large areas. Briefly the advantages are good spatial resolution, small scattering, and large area coverage. A disadvantage is slower resolving time compared to counter hodoscopes.

These properties indicate an application to multi-particle detection systems. Their good multi-track efficiency and spatial resolution is necessary for reconstruction of multiprong events. Although their resolving time is one micro-second, their excellent spatial resolution causes them to be used wherever a digitizing plane is needed.

The real technical hurdle to overcome with wire spark chambers is the readout system. To date, two systems have been in general use: magnetostrictive wires and ferrite cores. Neither of these systems works well, or at all, in a magnetic field; and it is in the magnetic field of a spectrometer that one needs them the most. A promising technique is an analogy of the core system in which the ferrite core on each chamber wire is replaced by a non-magnetic storage device - a capacitor or transistorized storage. The memory time of such a device is not infinite, but is amply adequate to permit the on-line computer to read it as desired. One such system is in an advanced stage of development, referred to as the FET (field effect transistor) system. It is scheduled to be used in an experiment soon, so we should have field experience available.

The track detector with greatest promise for the future is the proportional mode wire chamber. Further develop-ment must be done, however, to make it competitive with the spark mode wire chamber. Its inherent advantages are fast time resolution, less than 100 nanoseconds, continuous (non-pulsed) operation and extremely high multi-track efficiency. In its present form these chambers are used in experiments with 2 mm wire spacing, or a ±1 mm spatial resolution. This must be improved. Another technical problem is presented by the very low (a few millivolts) signal output from the chamber wires. This not only means a costly amplification system, it also means that the system is sensitive to background electrical noise, such as from magnet power supplies, high voltage pulsers, beam separators, etc. This problem can be solved, but will probably require some tricks like differential amplifiers and large filter networks.

Proportional wire chamber development is in progress at NAL. To date, some test chambers with 1 mm wire spacing have been built, and tested in a secondary particle beam at ANL. We find that a spatial resolution of ±0.5 mm was reached. We believe even higher resolutions may be obtainable. Because these chambers have very thin wires (20μ or less) and operate at atmospheric pressure with small gaps, they provide a very small interaction probability for incident particles. A chamber of this type is capable of counting about 10^6 pulses per wire per second, can provide good timing information, is capable of operation in magnetic fields, and has good efficiency for multiparticle detection.

(iii) Triggering Systems

Details of triggering systems are very experiment-specific. We should not discuss complete triggering arrangements, therefore, until specific experiments have been approved. The time coincidence of the particles involved in a reaction is determined by fast logic circuitry which is associated with the fast-response particle detectors such as scintillation counters. This logic circuitry is capable of faster rise times than are used in readout systems and digital computers.

Mass determination is made with the fast electronics. A variety of Čerenkov counters will be needed. Threshold, differential, DISC-type, and also large-aperture Čerenkov counters capable of simultaneously detecting more than one particle and its mass, will be required.

The fast trigger electronics can be standard, commercial (NIM) circuitry or its successor. It can be readily modified and extensive development work is not anticipated. It must, however, have the necessary latches for interfacing to the on-line computer. Much of the general purpose electronics equipment will be supplied from the pool of such equipment at the Laboratory. This pool is called PREP, which stands for Physics Research Equipment Pool.

(iv) Readout Systems and On-Line Computers

The computer needs for on-line experiments fall into two categories. The first is the collection and recording of data, and the monitoring of the experimental equipment for proper operation. The second is analysis of the data through to the final histograms. The first category obviously requires a computer directly attached to the experiment and any breakdown of it stops the experiment. The analysis of data can take place at a later time and at another place, but it is highly desirable to have some on-line analysis of data to guide the physicist. In fact, it is just this aspect of on-line experiments which lifts them above the photographic technique. The on-line computer (perhaps a PDP-15 or the equivalent) is, in practice, the control room for the experiment. Through it the physicist communicates not only with the detectors and other components of his experiment, but also with a larger computer in which final real-time (on-line) analysis of some of his data takes place. In some complicated experiments, the data collection and data analysis tasks will be combined into one computer (perhaps a PDP-10 or the equivalent).

The bulk of the data comes in through a fast data channel to the core memory of the computer. The memory serves as a buffer until the data is stored on magnetic tape or is sent on for analysis. This buffering function requires that the memory have a fast cycle time and a size adequate to handle the expected amount of data during at least one burst of the accelerator. In addition, the memory must hold programs used for monitoring operations during their execution. The programs will reside, when not executing, on a program disk or similar moderately slow-access storage.

3. Bubble Chamber Plans

Up until about November of 1969, our work on a large bubble chamber, which was primarily justified by the high energy neutrino physics possibilities, were devoted to studying the proposed 25-ft., $100m^3$ cryogenic bubble chamber. In the spring of 1969, the AEC provided design funds for the 25-foot chamber, and a design report on this chamber was completed in October 1969. However, the President's Budget for FY-1971 did not include any funds for initiation of construction of the chamber. It was then decided to construct a somewhat smaller chamber than the 25-foot chamber, at NAL, with the use of the yearly capital equipment funds. Our thinking about these matters has been dominated by the desire to have at NAL a bubble chamber which is suitable for neutrino experiments, which is coincident with the initial turn-on of Area #1 for experiments halfway through FY-1973. Under normal circumstances, it would not be possible to design and construct a large bubble chamber in such a short time. However, the BNL Bubble Chamber group has a design which is almost complete for the expansion of their 7-ft. 10,000-liter "test chamber", to a 14-ft. diameter sphere which provides a chamber of about 30,000 liters capacity, of which about 25,000 liters is visible to the three cameras. This design includes provision of a 30-kG superconducting analysis magnet.

At NAL, we are designing and initiating construction of a 15-ft. bubble chamber which is closely similar to, and in many respects identical to, the BNL design discussed above. The chamber is planned to be ready for experimental use in January, 1973. The first commitments for large items of equipment will be made in the fall of 1970, and the first cooldown is planned for July 1972. The capital cost of the chamber will be about 5 million dollars.

A cross-sectional view of the 15-foot chamber is shown in Fig. 8. No other specific plans for other bubble chamber installations at NAL have been made. A number of possible second bubble chambers have been, and are, under intensive investigation. The possibilities includes (a) a rapid- cycling $\sim$ 1-meter chamber for use in a 'hybrid' mode, in association with counter and spark chamber detector arrangements; (b) the transfer to NAL of an existing, high precision 1-2 meter bubble chamber; (c) the transfer to NAL of the ANL twelve-foot bubble chamber at some time in the future.

VII. COSTS AND SCHEDULES

At this early date in the design of the experimental areas and detection equipment, detailed cost estimates have not yet been prepared. However, in order to indicate the approximate expected cost levels, we show in Table VI below the January 1970 6-year forecast in capital equipment expenditures for the experimental areas.

Table VI

Equipment Cost Projections

Item	Cost thru FY75 (M$)	% of Total Cost
Secondary beam equipment	24	26%
Experimental equipment	7.5	8%
Shielding	8.5	9%
Analysis Magnets	10.5	11%
Spectrometer systems (including detectors)	12	13%
Bubble chamber	5	6%
Computers	22	24%
Data analysis	3	3%
	92.5	100%

In Table VII, we give a summary of construction costs that were originally estimated in the January 1968 NAL Design Report.

TABLE VII.

	M$
Construction of experimental areas	11
Shielding in experimental areas	4
External proton beam and target stations	10
EDIA, AEM, escalation, contingency	12
TOTAL	37

Schedules

The planned schedules milestone dates for experimental Area #2 are shown in Table VIII.

TABLE VIII
Schedules --- Area 2

Event	Target Area 2	Exp'l Area 2
100% Title I	5/15/70	9/01/70
Final Title I Report	6/01/70	9/15/70
100% Title II	8/15/70	1/15/71
Advertise for bids	9/01/70	2/01/71
Let contract	10/15/70	3/15/71
Complete construction	1/01/72	3/01/72
Start instllation of magnets	10/01/71	1/01/72
Ready for tuning secondary beam	--	5/01/72
Experimental use	7/01/72	7/01/72

The planned schedule milestone dates for Experimental Area #1 are shown in Table IX.

TABLE IX.

Schedules --- Area 1

Event	Target Area 1	Experimental Area 1
100% Title I	11/01/70	12/15/70
Final Title I Report	11/15/70	1/15/71
100% Title II	4/15/71	6/01/71
Advertise for bids	5/01/71	6/15/71
Let contract	6/15/71	8/01/71
Complete construction	8/72	11/01/72
Start installation of magnets	5/72	--
Ready for tuning secondary beam	12/72	--
Experimental use	1/73	1/73

VIII. FUTURE POSSIBILITIES

In this section, we conclude our report with a brief mention of a number of future possibilities at NAL.

1. Experimental Area #3

It is planned to start design of Area #3 in 1971, with the area to be ready for initial experimental use about 1974. In Area 3, it is hoped to be able to provide those beams and facilities which were omitted in Areas 1 and 2, and which are suggested by the initial research results in these two areas. Area #3 will be designed for use with 500 GeV protons. Other areas will be built as the experimental need develops.

2. Intersecting Storage Rings

There have been a number of studies made of possible storage ring facilities at NAL. Among these is a detailed design and cost study which was made in the summer of 1968 for intersecting 100 GeV-100 GeV proton-proton storage rings. No decision has yet been made to seek funds for any storage ring facilities.

3. 25' Bubble Chamber

After the 15' bubble chamber has been used for several experiments, it may become apparent that a much bigger chamber would be very desirable for certain classes of important experiments at NAL. A decision to plan to build a very large bubble chamber at NAl may then be made in the mid-1970's. It might be similar to the 25' bubble chamber which has already been designed.

Master Site Plan
(April 1, 1970)

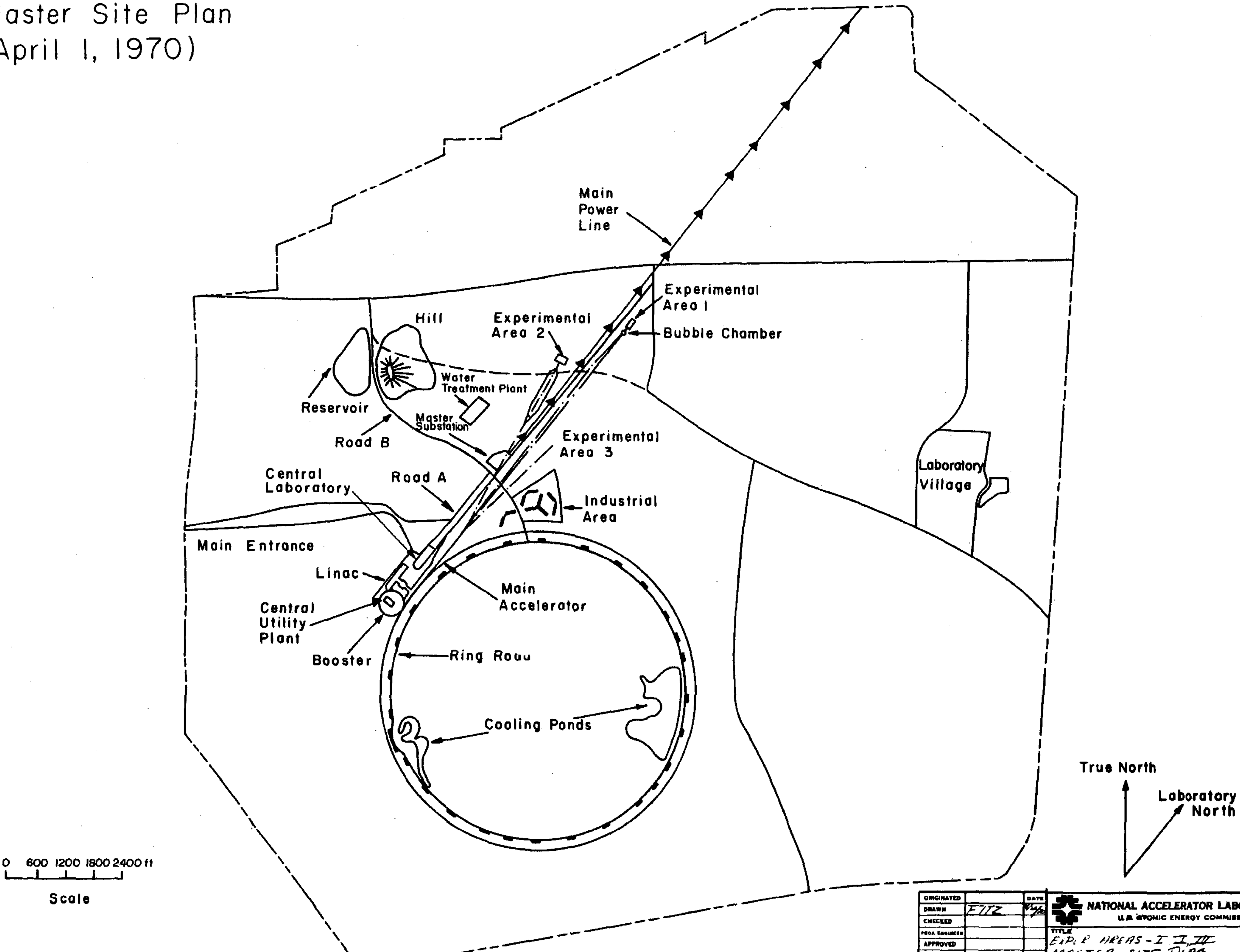
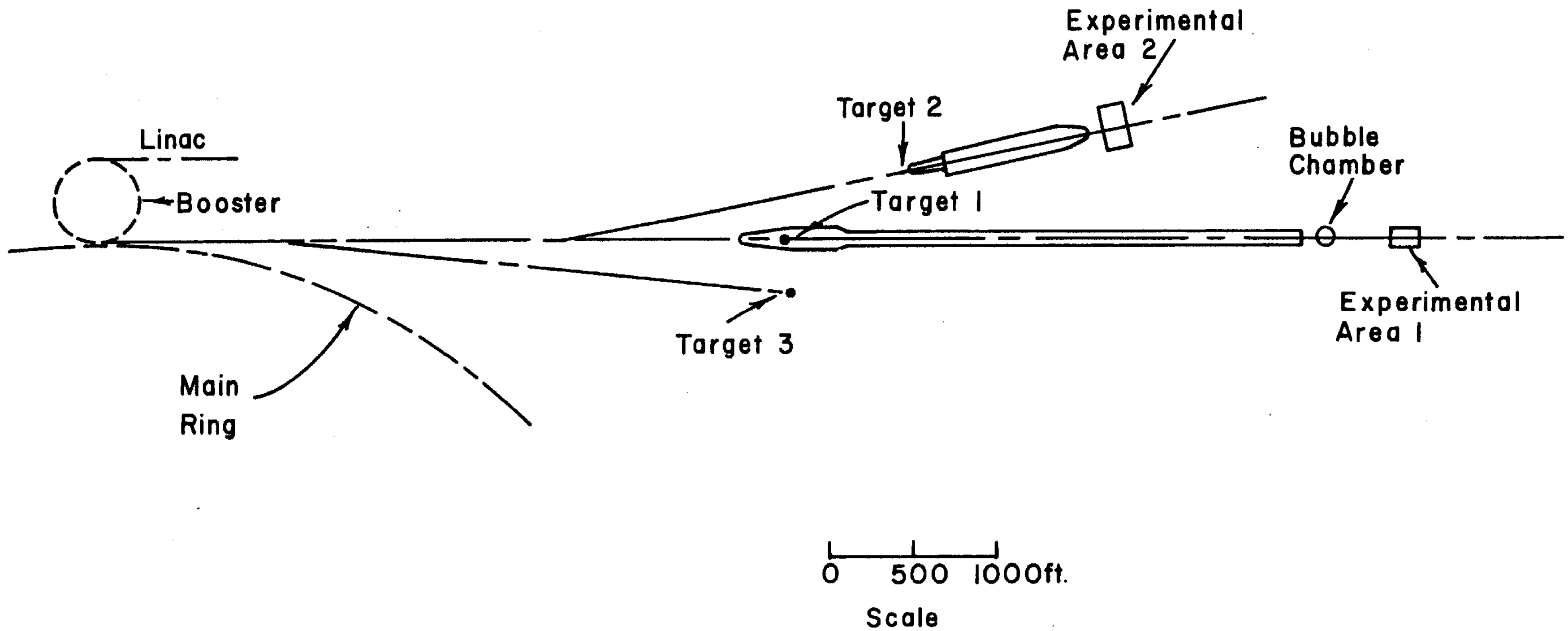


Figure 1.

ORIGINATED		DATE	NATIONAL ACCELERATOR LABORATORY U.S. ATOMIC ENERGY COMMISSION
DRAWN	FITZ		TITLE EXPER AREAS - I II, III MASTER SITE PLAN
CHECKED			
PROJ. ENGINEER			
APPROVED			
SCALE	SHEET	DRAWING No. 0110.1 - MC - 7370	REV.



Layout of Experimental Beam Areas

Figure 2.

ITEM No.	QTY. REQ'D	IDENT. No.	DESCRIPTION

LIST OF MATERIALS OR PARTS

SYM | LOCATION. DESCRIPTION. BY. DATE | REVISIONS

UNLESS OTHERWISE SPECIFIED
TOLERANCES:

FRACTIONS:	DECIMALS:	ANGLES:
±	±	±

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DIMENSIONING IN ACCORD WITH USASI Y14.5-1966

USED ON DWG. NO.

		DATE
ORIGINATED		
DRAWN	T.Y. 6-16-	70
CHECKED		
PROJ. ENGINEER		
APPROVED		

NATIONAL ACCELERATOR LABORATORY
U. S. ATOMIC ENERGY COMMISSION

TITLE
LAYOUT OF EXPERIMENTAL BEAM AREAS

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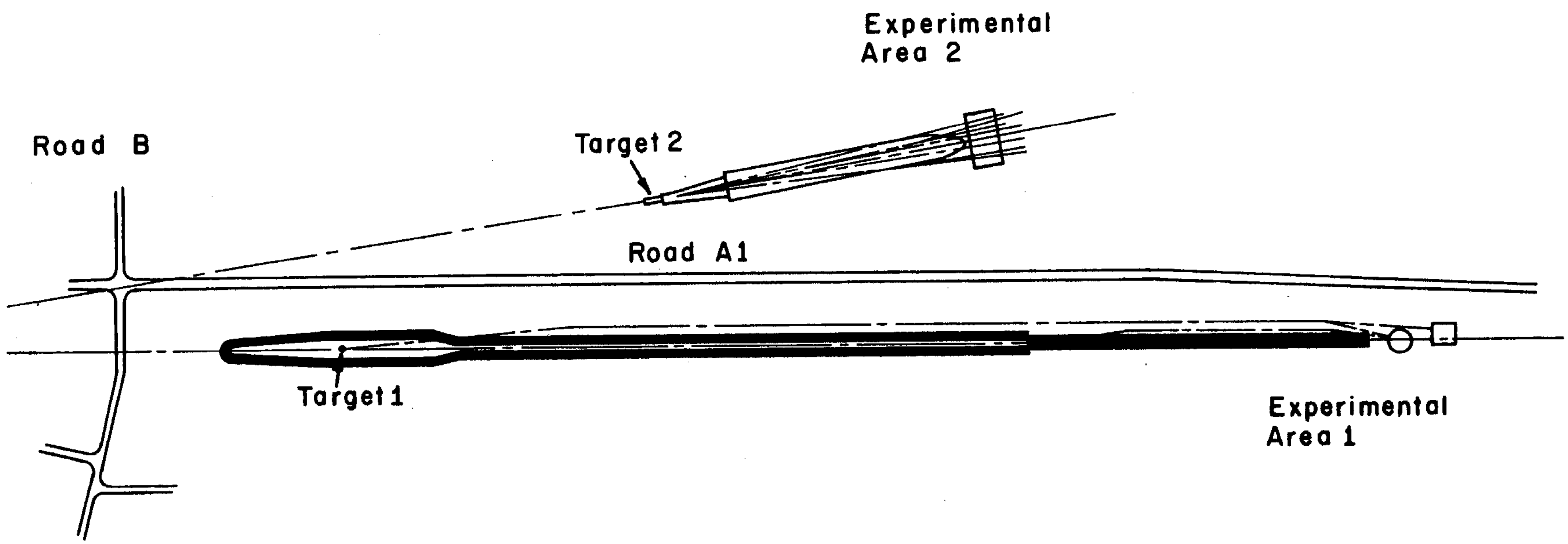
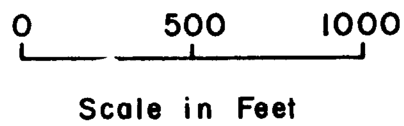
—	OF	2200-MB- 7460	

TM-257



Areas 1 & 2



			NATIONAL ACCELERATOR LABORATORY U.S. ATOMIC ENERGY COMMISSION			
ORIGINATED		DATE				
DRAWN	FITZ	9/30/70				
CHECKED						
PROJ. ENGINEER			TITLE EXPERIMENTAL AREA 1&2 PLAN VIEW			
APPROVED						
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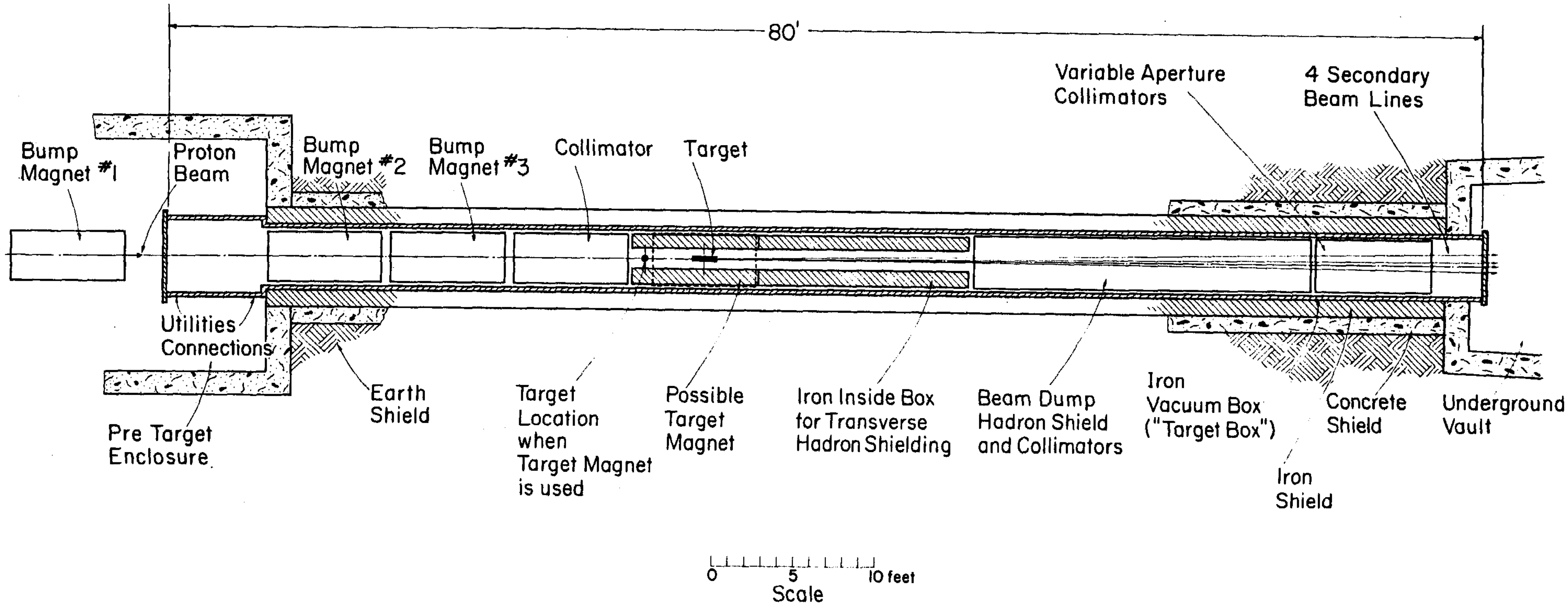
Figure 3.

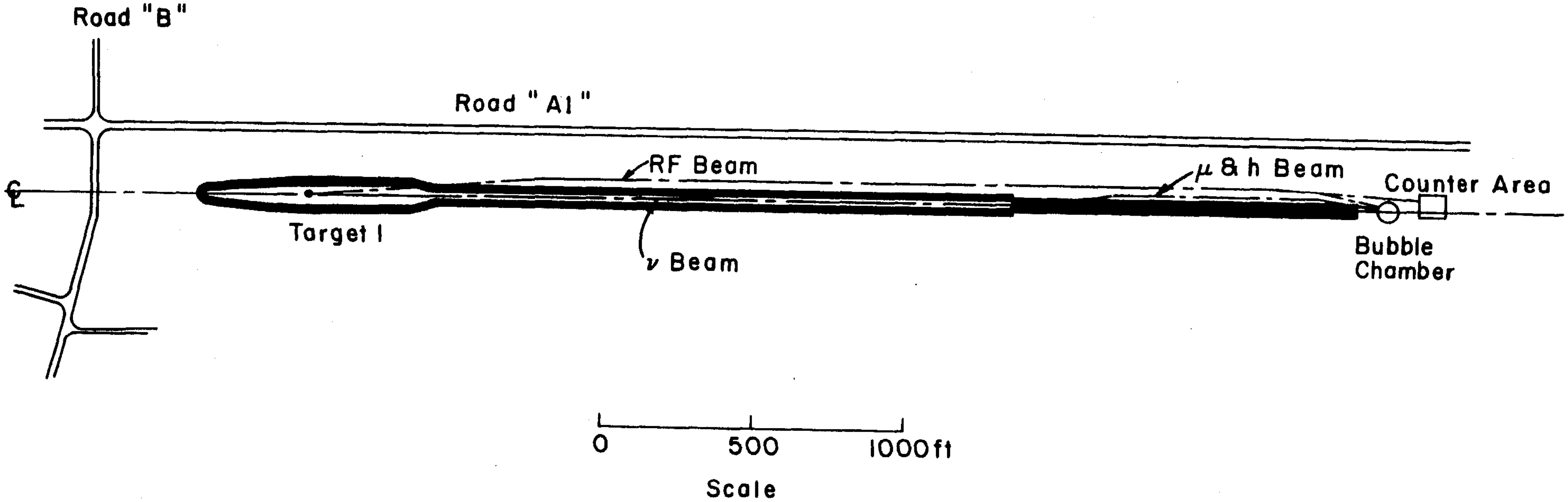
TM-257



Area #2 Target Box, Possible Load Configuration

Figure 4.

TM-257



Experimental Area I

ORIGINATED		DATE	NATIONAL ACCELERATOR LABORATO
DRAWN	FITZ	4/4/70	U. S. ATOMIC ENERGY COMMISSION
CHECKED			TITLE
PROJ. ENGINEER			EXPERIMENTAL AREA # I
APPROVED			PLAN VIEW
			SCALE 1:50 = 500 FT. · SHEET OF · DRAWING No. 2211.1-MB-7368

Figure 5.

TM-257

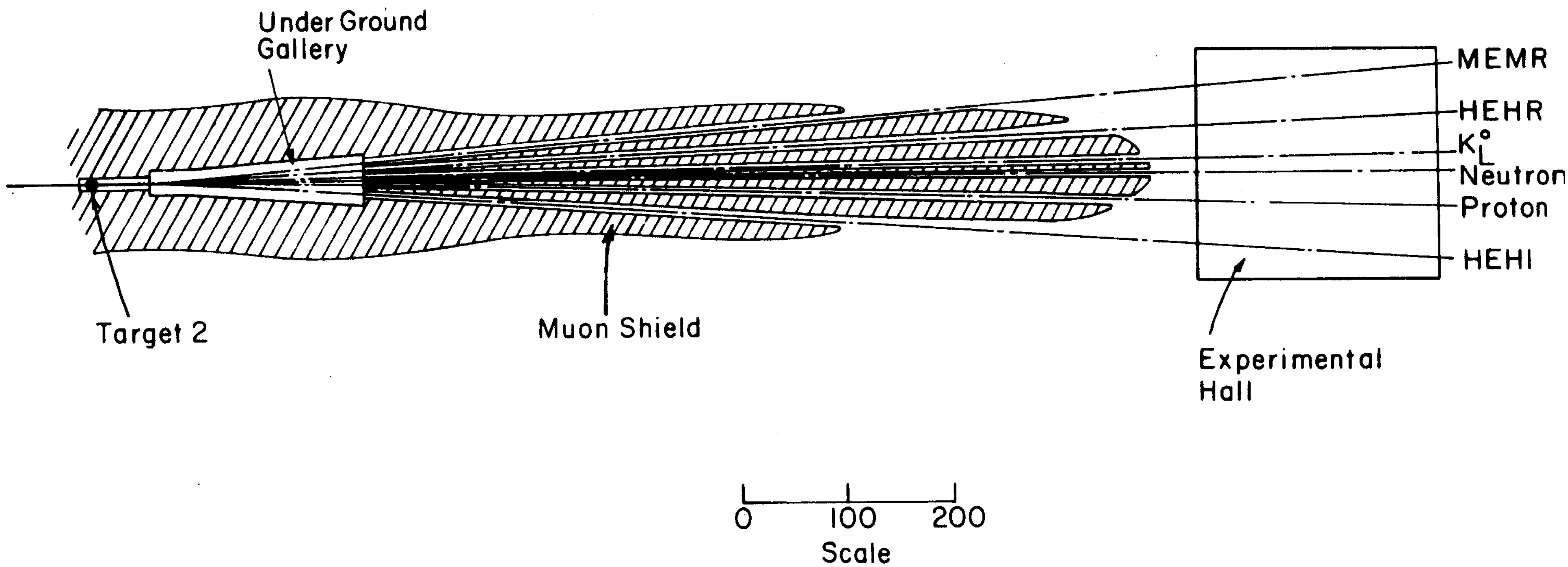
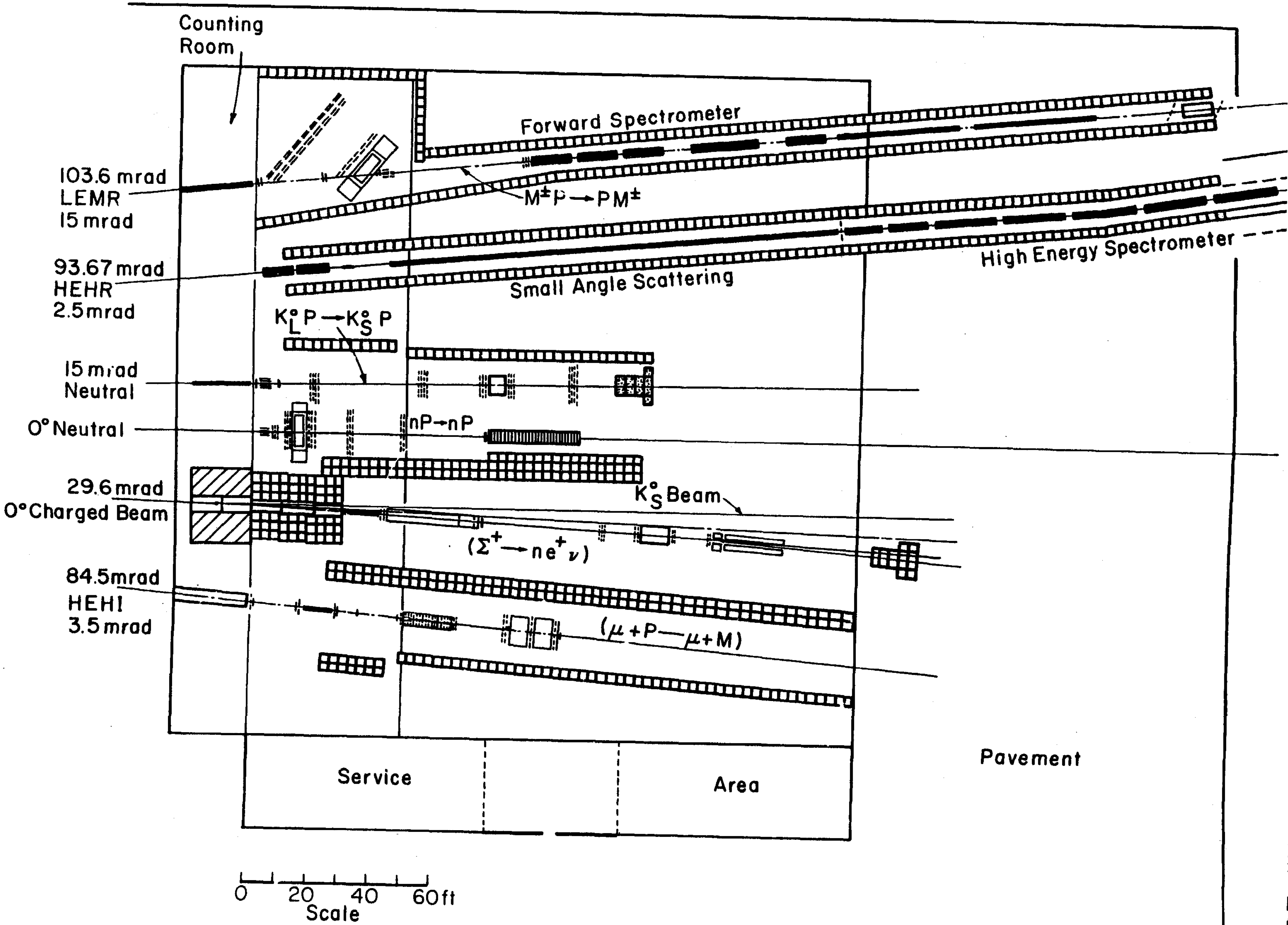


Figure 6, Experimental Area 2

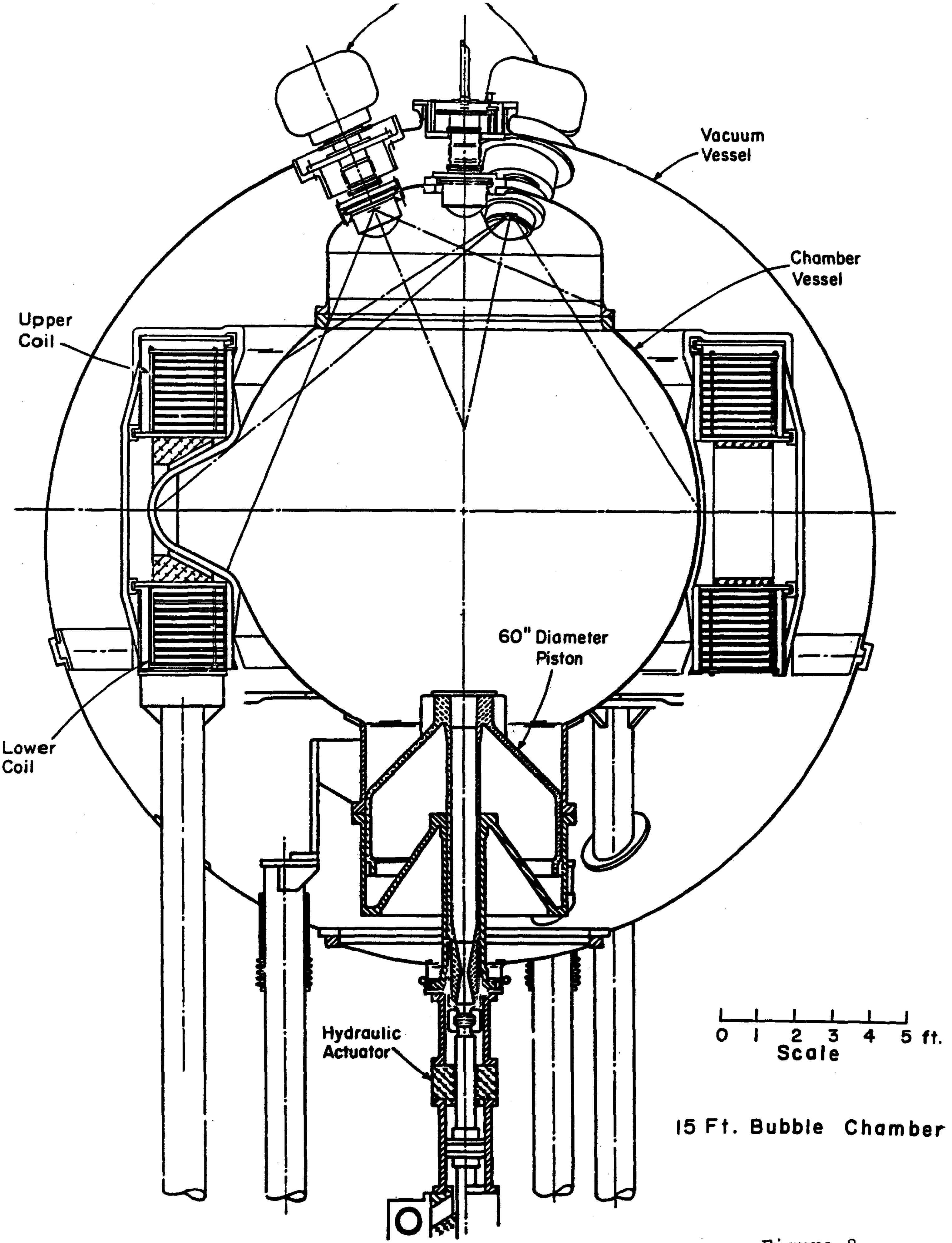
TM-257



Experimental Hall — Area 2

Figure 7.

TM-257



15 Ft. Bubble Chamber

Figure 8.